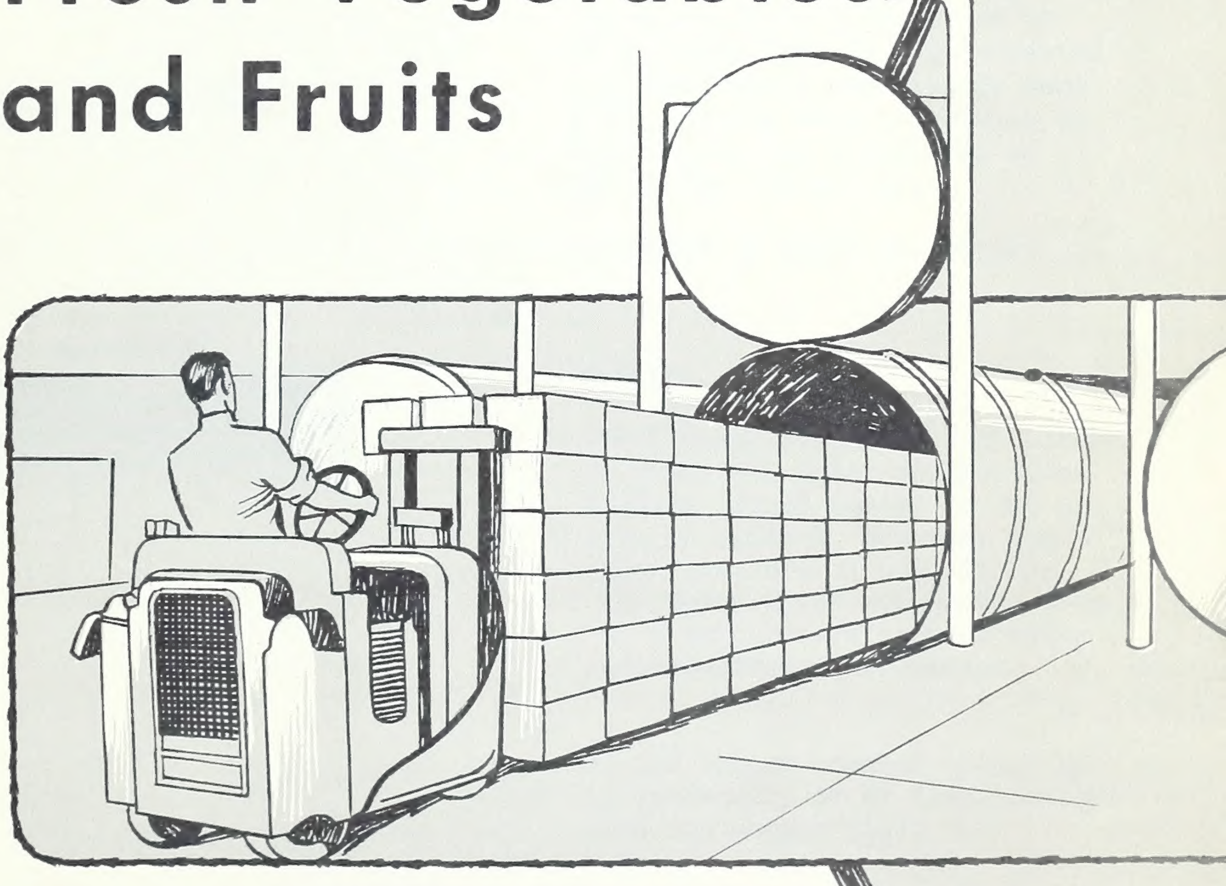
AMS - 107

Vacuum-Cooling Fresh Vegetables and Fruits



UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Marketing Service
Washington 25, D. C.

Agriculture-Washington

April 1956

VACUUM-COOLING FRESH VEGETABLES AND FRUITS

By

B. A. Friedman, senior plant pathologist, and
W. A. Radspinner, associate horticulturist
Biological Sciences Branch
Agricultural Marketing Service
New York, N. Y.

Vacuum-cooling for agricultural produce was used commercially for the first time in 1948 when 34 carloads of lettuce were cooled by this method at Salinas, Calif. Since then development has been so rapid that it was estimated that about 40 to 85 percent of the lettuce crop of California and Arizona were vacuum-cooled in 1954 (4, 14).[1/] Vacuum-coolers for lettuce have been built in Texas, Wisconsin, and Canada. A similar installation for the precooling of prepackaged vegetables has been in use since 1950 in New Jersey (9).

The purpose of this report is to summarize results of tests on vacuum-cooling of vegetables and fruits to date.

PRINCIPLES OF VACUUM-COOLING

Evaporative cooling was utilized early in the history of man to cool water as in earthenware jugs. Cooling towers and spray ponds are later applications of the same principle. At normal atmospheric pressure (29.92 inches or 760 mm. of mercury) water boils at 212° F. As the pressure is reduced, however, the boiling point of water is reduced until at a partial pressure of 0.18 inches (4.6 mm.) of mercury, water boils at 32° (15). The water which evaporates from fresh fruits and vegetables cools the commodity to a temperature corresponding to the evaporating temperature of water at the reduced pressure or vacuum attained (16).

In commercial practice, air is pumped out of the vacuum chamber either by a multi-stage steam ejector system and barometric condenser, or by electrically driven mechanical pumps connected with refrigerated condensers (18).

TEMPERATURE CHANGES DURING VACUUM-COOLING

Relation of Ratio of Surface to Volume of Produce. The results obtained by the vacuum-cooling of a number of fruits and vegetables show that leafy vegetables, which have a large surface area for evaporation in proportion to their volume, are rapidly cooled (table 1). Commodities which have a somewhat smaller ratio of surface area to volume are generally less readily vacuum-cooled (table 2); fruits and vegetables which have a small evaporating surface in proportion to their volume are usually poorly cooled by vacuum methods (table 3).

1/ Underscored figures in parentheses refer to Literature Cited, page 11.

In addition to the surface-volume relationship, there is evidence that the rate of evaporation during vacuum-cooling is affected by the structure, tissue density, thickness of skin, and waxiness of the different fruits and vegetables.

Vacuum-Cooling of Wet and Dry Produce. Inasmuch as the temperature reduction during vacuum-cooling is the result of evaporation of water, some fruits and vegetables have been moistened with water to determine whether lower temperatures would result. The wetting of celery, cranberries, grapes, and mushrooms had little effect (table 4), whereas the wetting of strawberries caused a substantial cooling (fig. 1).

In tests to determine the effects of added moisture, celery, grapes, and strawberries were dry when removed from the vacuum chamber. Wet mushrooms felt slightly moister than dry mushrooms after vacuum-cooling, and in addition developed a slight brownish discoloration. Friedman (7) found that wet spinach remained wet after it had been vacuum-cooled for only 5 minutes.

Vacuum-cooling of strawberries, and possibly other commodities, might be practicable commercially if they were moist from rain, heavy dew, from being washed, or from application of fungicides in water. Vacuum-cooling might serve to dry moist commodities.

Wet- and Dry-bulb Temperature Readings During Vacuum Cycle. Vacuum-cooling of fresh fruits and vegetables must be controlled accurately to avoid the possibility of freezing. Vacuum methods have been used commercially to freeze shelled green peas (17). Wet-bulb thermometers generally are used for controlling the vacuum-cooling process. A dry-bulb thermometer alone would obviously be unsatisfactory to indicate commodity temperature. When lettuce temperatures were about 36° F. and the wet-bulb air temperature 32°, the dry-bulb temperature was 49.5°. By means of wet- and dry-bulb thermocouples, air temperature readings were taken during the vacuum-cooling of prepackaged vegetables (fig. 2). In the first part of the cycle, when pressure apparently was still high and the air was saturated with water vapor, wet- and dry-bulb temperatures were approximately the same. When the main vacuum booster valve was opened 5 1/2 minutes after the start of the vacuum cycle, the pressure dropped rapidly and the temperature spread between the wet- and dry-bulb readings increased until by 12 minutes after the start of the cycle there was a difference of 17 1/2 degrees.

Relation of Amount of Vacuum and Temperature. It was noted previously that the temperature at which water boils is determined by pressure. The lower the pressure, the lower the boiling temperature. This principle was demonstrated experimentally by vacuum-cooling spinach for 5 minutes at 2 different pressures, namely at 5.0 and 4.5 mm. of mercury. The pressures were measured by a McLeod gage. At the start the temperature of the spinach was 80° F. The temperature of the spinach vacuum-cooled at 5.0 mm. was 39°, while that at 4.5 mm. was 32°.

Effect of Initial Temperature on Cooling. To determine what effect the initial temperature has upon the rate of cooling, warm and cool loads of celery and lettuce were vacuum-cooled together. The results (figs. 3 and 4) show that the initial temperature of lettuce has little effect upon its final temperature. Experiments with spinach (7) showed the same results in this respect. The initial temperature of celery, on the other hand, has a marked effect upon its final temperature, a difference of about 10 degrees. This is probably due to the smaller surface area-volume ratio of celery.

Many inquiries have been received regarding the possibility of vacuum-cooling celery. This commodity is not readily vacuum-cooled (table 2). However, possibly a double vacuum cycle, i.e., two successive vacuum-coolings may be used for celery (fig. 4). If a double vacuum cycle is employed, observations should be made to see whether there is excessive shriveling. Other possible methods would be to lengthen the time under vacuum (9), to wet the celery prior to vacuum-cooling, or to use a greater vacuum (7). In the last method, however, the possibility of freezing, especially of the leaves, would have to be considered.

Relation of Type of Container to Rate of Precooling. Leafy vegetables which were packaged in cellophane bags, packed in cartons, and stacked solidly on pallets, were rapidly vacuum-cooled, whereas similarly handled commodities were cooled very slowly by means of conventional cooling in cold air (9).

In another experiment, lettuce was vacuum-cooled in fiberboard containers and in unlined, wooden, wirebound crates at the same time to determine the effect of type of container upon the rate of cooling. The results (fig. 5) give further evidence that a commodity which can be vacuum-cooled rapidly can be packed in any type of container without affecting significantly the rate of cooling if there are some openings to permit the escape of air and water vapor.

WEIGHT LOSS DURING VACUUM-COOLING

It has been supposed by some that considerable water is lost by evaporation during vacuum cooling. It has been calculated that to cool 100 pounds of coleslaw from 70° F. to 35° it is necessary to extract approximately 2,325 B.t.u. This would require the evaporation of about 2.2 pounds of water or about 2.2 percent of the weight. In actual practice, the weight loss of coleslaw during vacuum-cooling was about 2.0 percent (9). The weight losses of several commodities during vacuum-cooling are shown (table 5).

EFFECT OF VACUUM-COOLING ON QUALITY OF PRODUCE

Weight losses during vacuum-cooling are small, and shriveling or wilting in vegetables has not been a problem in commercial vacuum-cooling.

Brown spot of lettuce which is troublesome at times has been attributed to suffocation during vacuum-cooling (11). However, brown spot also occurs in lettuce which has not been vacuum-cooled. Further, some lettuce has been vacuum-cooled for 8 hours and then stored for 3 weeks at 38° F. without any evidence of suffocation or brown spot.2/

Apples, potatoes, and tomatoes have suffered some injury during vacuum cooling (6, 8), but no serious consideration has been given to cooling them by this process. Aside from these commodities, no impairment of either flavor or quality has been observed in other vacuum-cooled fruits and vegetables.

Trade publications have stated that the vacuum process destroys bacteria which cause decay in lettuce. No evidence has been seen to substantiate this statement. The resistance of bacterial cells to adverse conditions is well known and it is probable that if the vacuum were to rupture bacteria, it would also injure the vegetable cells. In fact, a common method of preserving bacteria is to freeze-dry them under extremely high vacuum.

Inhibition of decay by vacuum-cooling is probably a result of thorough precooling plus drying the surfaces of produce. Low temperature is the principal inhibitor of decay. In a comparison of dry-packed, vacuum-cooled lettuce and ice-packed, non-vacuum-cooled lettuce, little difference was found in the amount of waste under strictly controlled conditions (12).

SOME ECONOMIC CONSIDERATIONS OF VACUUM-COOLING

According to trade reports the initial investment for vacuum equipment is high, and apparently operation over long seasons is necessary to justify the costs involved. The latest development has been the construction of vacuum chambers large enough to accommodate a loaded refrigerator railroad car or truck trailer (13).

Vacuum-cooling has created a revolutionary change in the handling of lettuce. The process permits the use of any type of container for packaging. Lettuce can be packed in the field, eliminating the need for a packing house. It is no longer necessary to use packaged ice or to top-ice the lettuce in transit, and space is thus better utilized. Burkhart (2) has estimated that lettuce packing and shipping costs have been reduced 25 percent since the advent of vacuum-cooling.

It can be anticipated that if new large acreages are planted to lettuce, vacuum-cooling plants will be constructed. Also, there will probably be further refinements in vacuum-cooling of lettuce and its use extended to prepackaged lettuce.

Spinach, coleslaw, and mixed salad can be hydrocooled (flooded or immersed in ice water) prior to packaging, but by the time they are spun-dried and

---

2/ Unpublished data by G. L. Rygg and D. H. Dewey.

packaged an appreciable amount of refrigeration is lost. Vacuum-cooling permits cooling after the produce is bagged and packed in master containers. Vacuum-cooling has made possible the marketing of spinach, coleslaw, and mixed salad during hot weather when it previously was not economical because of decay.

Another advantage of the vacuum-cooling process is the rapidity with which commodities can be precooled. Indeed, the method is very frequently called "flash" cooling. Commercially, lettuce is precooled in about 30 minutes; prepackaged leafy vegetables are precooled in about 15 minutes.

The results to date indicate that vacuum-cooling may be suitable for several items not commercially precooled, such as strawberries, mushrooms, sweet corn, and possibly celery.

Injections of fungicidal gases and mixtures of carbon dioxide and oxygen during the vacuum process to lengthen shelf-life and inhibit decay may have possibilities but await future tests.

Table 1.--Effectiveness of vacuum-cooling vegetables with large surface area-to-volume ratio

Commodity 1/	Container	Duration of vacuum cycle	Temperature of commodity at - Beginning of cycle	End of cycle
		Minutes	°F.	°F.
Brussel sprouts	Quart cup	20	68	38
Cabbage	None	20	68	40
Coleslaw	Cellophane bag	20	67	34
Coleslaw	Cellophane bag	18	65	32-36
Endive	Crate	20	68	36
Endive, Belgian	Bundle	14	67	40
Escarole	Crate	20	68	36
Lettuce 2/	Crate	55	60-70	32-33
Lettuce 3/	Crate	20	72	32
Lettuce	Cellophane wrap	10	75	34
Lettuce	Carton	13	71	36
Lettuce	Carton	13	69	34
Parsley	Crate	20	68	34
Salad mix 3/	Cellophane bag	20	65	35
Soup mix 3/	Cellophane bag	20	62	34
Spinach	Cellophane bag	20	65	34
Spinach 3/	Cellophane bag	20	66	35
Spinach	Bushel basket	10	67	37

1/ Results were obtained by Friedman (7, 8, 9, 10), and from unpublished data unless otherwise indicated.

2/ Data from Clements (3).

3/ Data from Barger (1).

Table 2.--Effectiveness of vacuum-cooling vegetables with medium surface area-to-volume ratio

Commodity 1/	Container	Duration of vacuum cycle	Temperature of commodity at--	
			Beginning of cycle	End of cycle
		Minutes	°F.	°F.
Artichoke	Crate	16	66	50
Asparagus 2/	Bunch	10	64	36
Beans, snap	Hamper	20	80	60
Beans, snap	Hamper	12	69	45
Beans, snap	Cellophane bag	14	70	43
Broccoli	Wirebound crate	20	65	45
Broccoli	Crate	13	67	44
Cauliflower	Crate	20	76	44
Cauliflower	Crate	13	62	46
Celery	Cellophane bag	20	68	42
Celery 3/	Cellophane bag	20	66	47
Celery	Crate	13	70	47
Celery	Crate	13	77	53
Corn, sweet, husked 2/	Cellophane tray	10	59	36
Corn, sweet, husked 4/	Cellophane tray	10	75	39
Corn, sweet, unhusked	Crate	20	83	43
Leeks	Wirebound crate	20	68	36-40
Mushrooms	Basket (9 lb.)	20	67	39
Mushrooms	Basket (9 lb.)	16	66	35
Mushrooms	Basket (9 lb.)	15	70	45
Mushrooms	Carton (3 lb.)	15	69	46
Mushrooms	Prepackaged 5/	15	68	43
Mushrooms	Prepackaged 6/	15	70	45

1/ See footnote 1, table 1.

2/ Vacuum was drawn with experimental equipment to 3.3 mm. mercury (measured with a McLeod gage) at which point water boils at 25° F. Ice formed on spears of asparagus, but none on sweet corn.

3/ Data from Barger (1).

4/ Vacuum was drawn to 3.8 mm. mercury.

5/ Six pints packed in a cellophane-overwrapped wooden basket in a master carton.

6/ One pound cellophane overwrapped, perforated tray.

Table 3.--Effectiveness of vacuum-cooling some vegetables and fruits with small surface area-to-volume ratio

Commodity 1/	Container	Duration of vacuum cycle	Temperature of commodity at-- Beginning of cycle	End of cycle
		Minutes	°F.	°F.
Apples, Golden Delicious	None	45	79	50
Carrot, roots 2/	Crate	20	66	60
Cranberries 3/	Cellophane bags and trays	14	74	68
Cucumbers	Baskets	20	78	73
Grapes, Ribier 4/	None	20	69	63
Grapes, seedless 4/	None	20	70	64
Grapes, seedless	Lug	20	64	40-45
Grapes, Emperor	Lug	15	63	50
Oranges	None	10	75	72
Peppers, bell	Hamper	20	80	50
Potatoes, intact 5/	None	30	65	57
Potatoes, skinned 5/	None	30	65	45
Strawberries 4/	None	20	65	53
Strawberries, dry	Cup	13	64	51
Strawberries, wet	Cup	13	65	38
Tomatoes	Cellophane tray	10	73	67
Tomatoes	Cellophane tray	20	77	71

1/ See footnote 1, table 1.

2/ The tops attached to these roots were cooled simultaneously to 38° F.

3/ Unpublished data by H. W. Hruschka and J. Kaufman, 1954.

4/ Data from Barger (1).

5/ Data from Dewey (6).

Table 4.--Temperature changes in vacuum-cooled wet and dry fruits and vegetables

Commodity	Container	Duration of vacuum cycle	Wet			Dry		
			Temperature of commodity at--		Drop in temperature	Temperature of commodity at--		Drop in temperature
			Beginning of cycle	End of cycle		Beginning of cycle	End of cycle	
		Minutes	°F.	°F.	°F.	°F.	°F.	°F.
Celery	Crate	12	54	38	16	52	41	11
Celery	Crate	14	62	44	18	56	44	12
Cranberries[1/]	Cellophane bag or tray	19	71	64	7	72	68	4
Grapes	Lug	15	64	51	13	64	51	13
Mushrooms	Basket	17	70	43	27	70	45	25
Strawberries	Cup	13	65	38	27	64	51	13

1/ Unpublished data from Hruschka and Kaufman, 1954.

Table 5.--Effect of vacuum-cooling on weight losses of vegetables

Commodity	Container	Duration of vacuum cycle	Weight loss
		Minutes	Percent
Celery 1/	Cellophane bag	30	2.7
Cranberries 2/	Cellophane bag or tray	20	3/ 1.0
Coleslaw 4/	Cellophane bag	18	2.0
Lettuce 5/	None	8	3.4
Lettuce 5/	None	15	4.7
Salad mix 1/	Cellophane bag	30	3.2
Salad mix 4/	Cellophane bag	18	2.6
Soup mix 1/	Cellophane bag	30	2.2
Spinach 1/	Cellophane bag	30	3.2

1/ Data from Barger (1).

2/ Data from Hruschka and Kaufman 1954.

3/ Cranberries cooled only 6 degrees.

4/ Data from Friedman (9).

5/ Data from Dewey (5).

LITERATURE CITED

(1) Barger, W. R.
1949. Further tests with vacuum precooling on fruits and vegetables, Salinas, Calif., August 1949. U. S. Bur. Plant Indus., Soils, & Agr. Engin., Handling, Transportation, & Storage Off. Rept. 244.

(2) Burkhart, L.
1953. Vacuum cooling Arizona lettuce. West. Grower & Shipper 24(4): 20-22.

(3) Clements, J.
1949. Report on vacuum cooling of lettuce, Salinas, Calif., June 13-15, U. S. Bur. Plant Indus., Soils, & Agr. Engin., Handling, Transportation & Storage Off. Rpt. 243.

(4) Cramer, F.
1954. Vacuum cooling. Market Growers Jour., Dec., p. 37.

(5) Dewey, D. H.
1950. Air blast and vacuum cooling of lettuce temperature and moisture changes. Amer. Soc. Hort. Sci. Proc. 56: 320-326.

(6) ________
1952. Evaporative cooling of fruits and vegetables. Refrig. Engin. 60(12): 1281-1283, 1295.

(7) Friedman, B. A.
1949. Preliminary observations on vacuum cooling of fruits and vegetables. U. S. Bur. Plant Indus., Soils, and Agr. Engin., Handling, Transportation & Storage Off. Rpt. 245.

(8) ________
1949. Vacuum cooling of fresh vegetables. Pre-Pack-Age 3(3): 28-29.

(9) ________
1951. Vacuum cooling of prepackaged spinach, coleslaw, and mixed salad. Amer. Soc. Hort. Sci. Proc. 58: 279-287.

(10) ________
1952. Vacuum cooling of vegetables and fruits. Pre-Pack-Age 5(12): 18-20, 22, 25.

(11) ________
1954. Brown spot complex of head lettuce on eastern markets. Plant Dis. Rptr. 38(12): 847-851.

(12) Friedman, B. A. and Kaufman, J.
1953. Comparison of the storage life of vacuum-cooled and ice-packed lettuce. U. S. Bur. Plant Indus., Soils, & Agr. Engin., Handling, Transportation, & Storage Off. Rpt. 309.

(13) Fuller, H. C.
1954. First carloads of lettuce handled by new method. The Packer, Nov. 6, p. 50.

(14) Hayes, H. P.
1954. Vacuum cooling of produce. Refrig. Engin., 62: 47-49, 90.

(15) Hodgman, C. D.
1949. Handbook of Chemistry and Physics. Ed. 31, Cf. p. 1852-1853, Chem. Rubber Pub. Co., Cleveland, Ohio.

(16) Kasser, M.
1944. Method and apparatus for treating perishable articles. U. S. Patent Off., No. 2,344,151, p. 6.

(17) Mazzola, L. C.
1946. "Flash freezing" of foods. Food Indus. 18(12): 73-77, 210, 212.

(18) Miller, I. C.
1952. Vacuum cooling saves costly process time. Food Engin., Oct., p. 104-111.

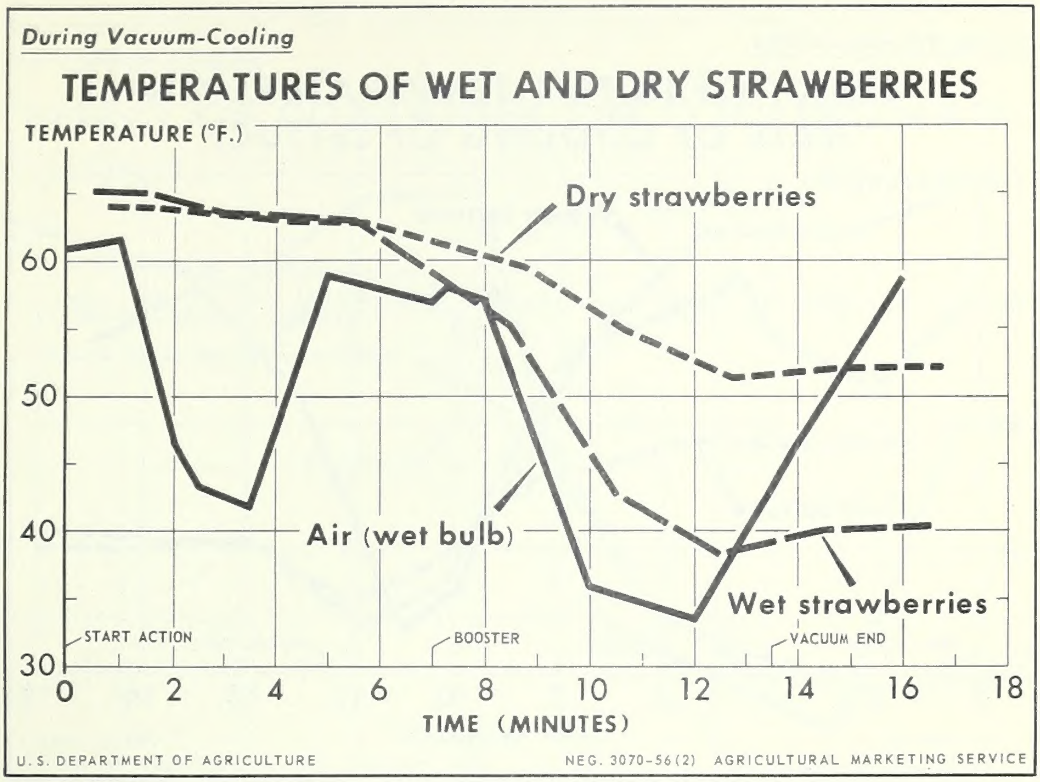


Figure 1

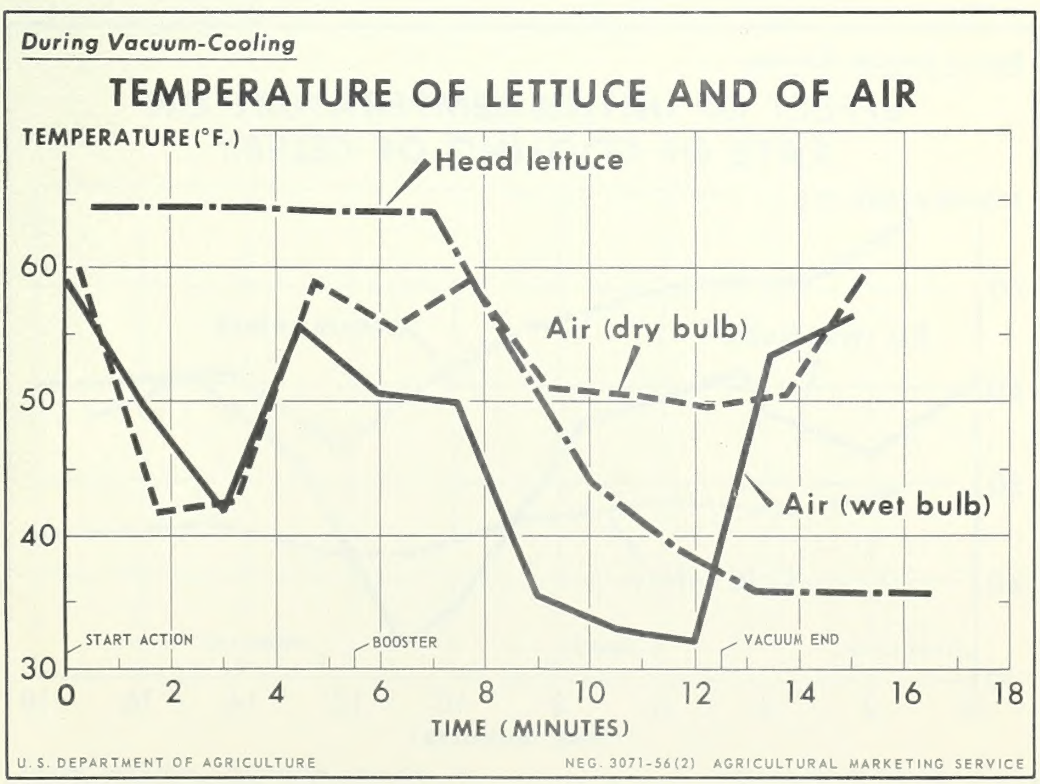


Figure 2

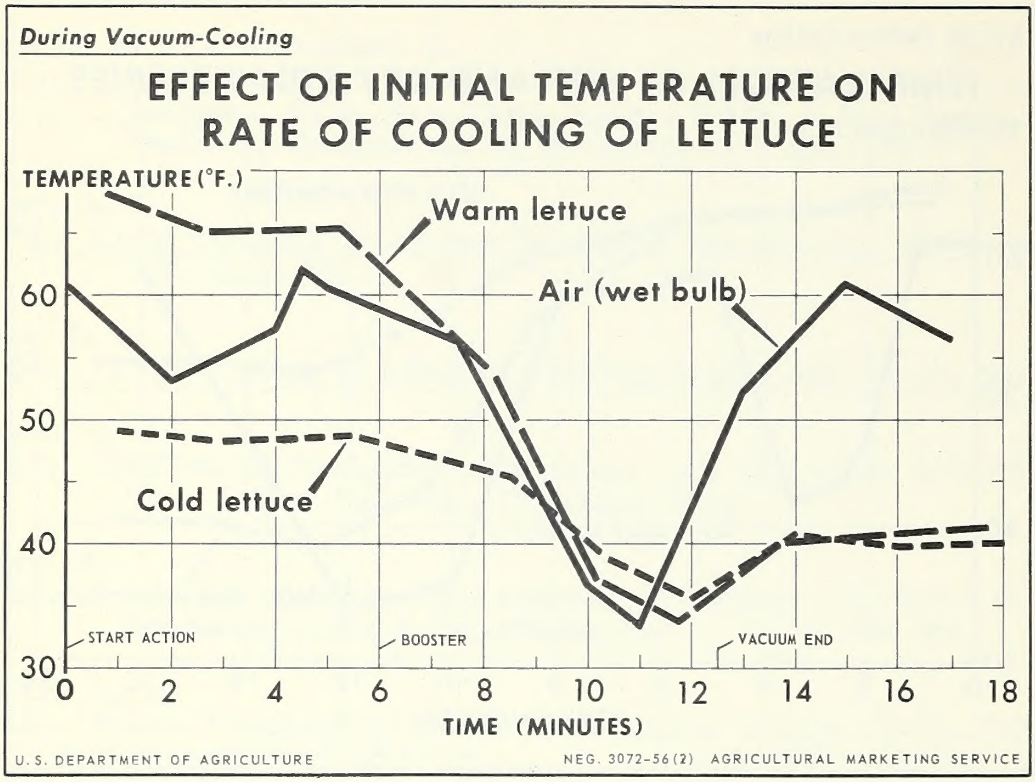


Figure 3

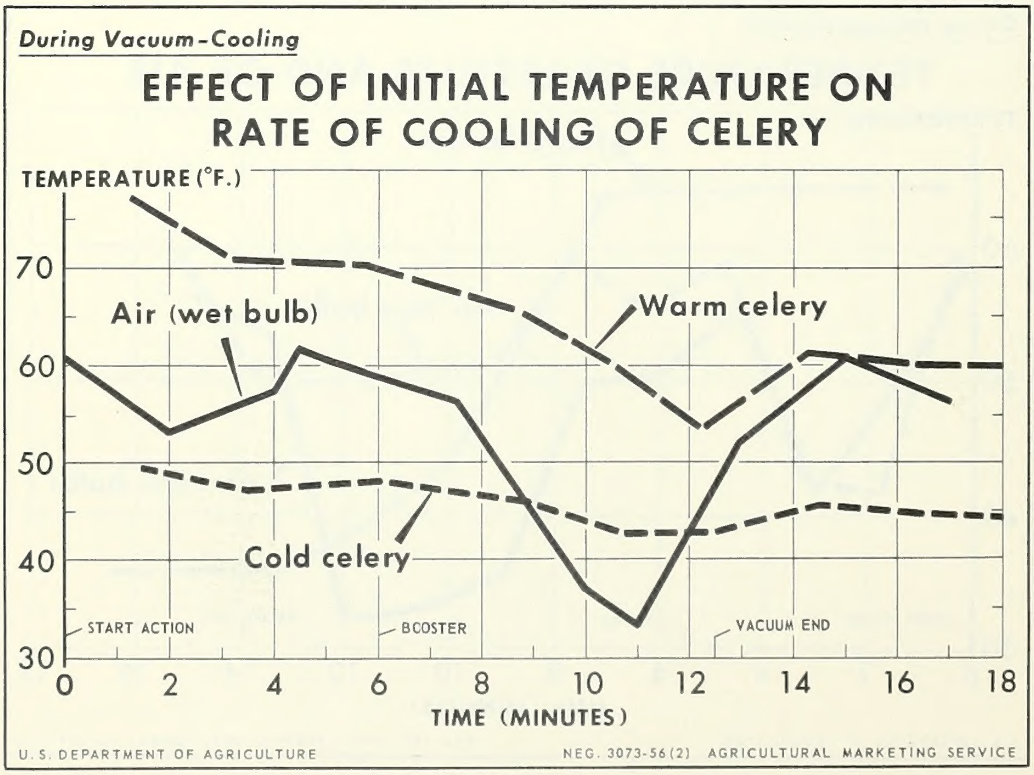


Figure 4

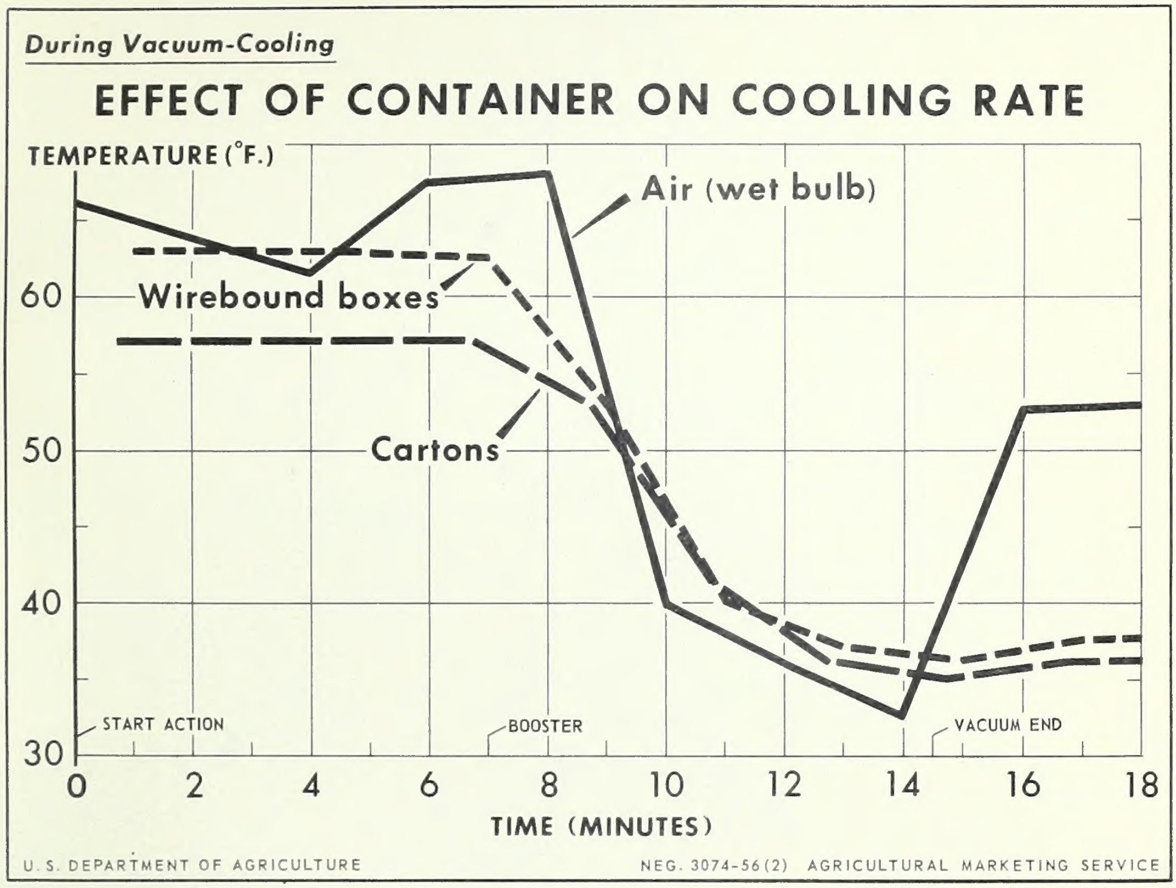

During Vacuum-Cooling
EFFECT OF CONTAINER ON COOLING RATE
TEMPERATURE (°F.)
Air (wet bulb)
Wirebound boxes
Cartons
60
50
40
30
START ACTION
BOOSTER
VACUUM END
0
2
4
6
8
10
12
14
16
18
TIME (MINUTES)
U. S. DEPARTMENT OF AGRICULTURE
NEG. 3074-56(2) AGRICULTURAL MARKETING SERVICE

Figure 5